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(54) **Liquid crystal display systems**

(57) In a liquid crystal matrix display system, in which the dielectric anisotropy is positive below a critical frequency *fc* lying within a range from 30Hz to 30KHz and is negative above *fc*, two-frequency matrix-addressing is effected by a high frequency f_H above *fc* and a low frequency f_L below *fc*, f_L or a multiple being synchronized with an addressing timing signal. R_1 to R_8 show the timing signals of the 1st to 8th rows; C_1 shows a first column data signal and its phase with the f_H ON waves A_1 to A_8 and B_1 to B_8 OFF waves; F_{11} shows an OFF signal across a cell in the first row and column; and F_{81} shows an ON signal across a cell in the eighth row and the first column. Alternatively the timing signals may be synchronized with f_H or submultiple, or ON and OFF timing signals and data signal may be not all equal in voltage.

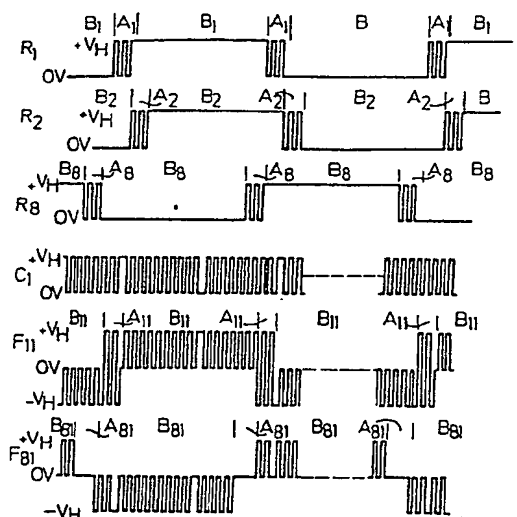
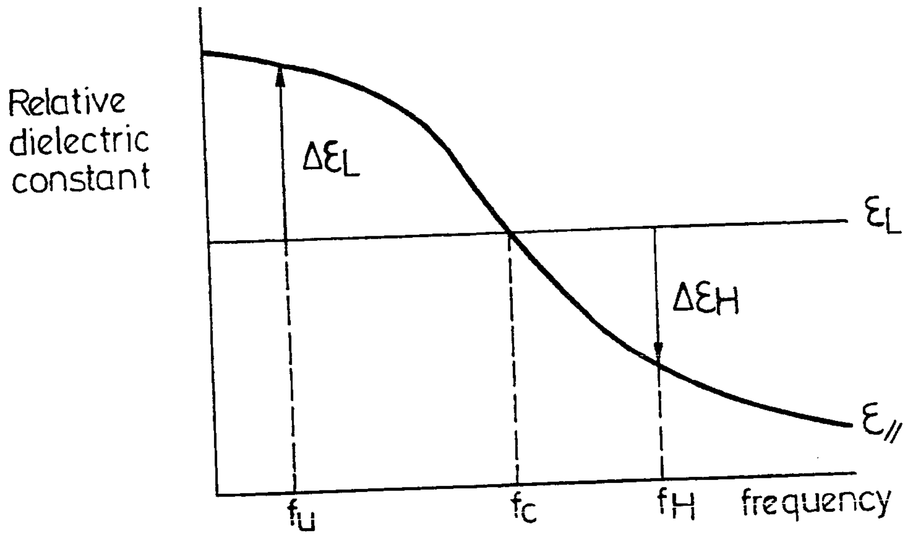


Fig. 5

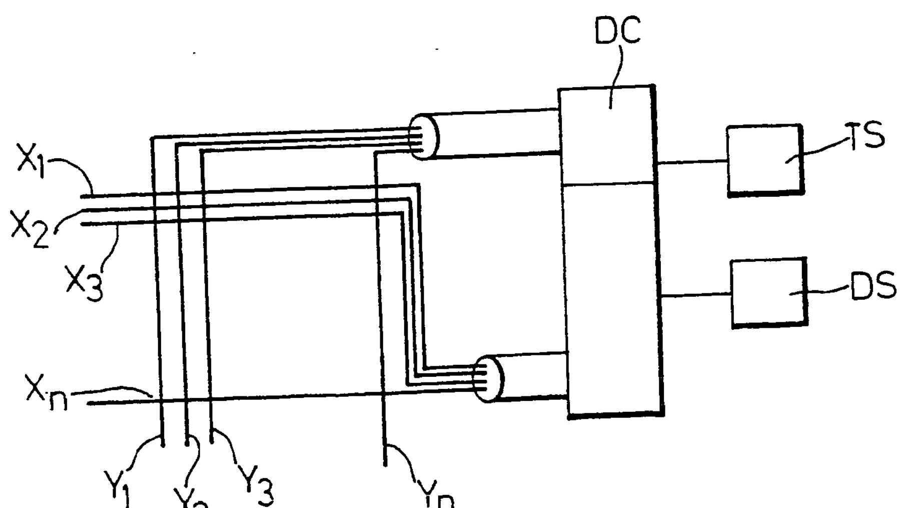
Certain of the mathematical formulae appearing in the printed specification were submitted in formal form after the date of filing.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.



Relative dielectric constant
ΔεL
εL
ΔεH
ε//
fu
fc
fH
frequency

Fig.1



DC
TS
DS
X1
X2
X3
Xn
Y1
Y2
Y3
Yn

Fig. Q

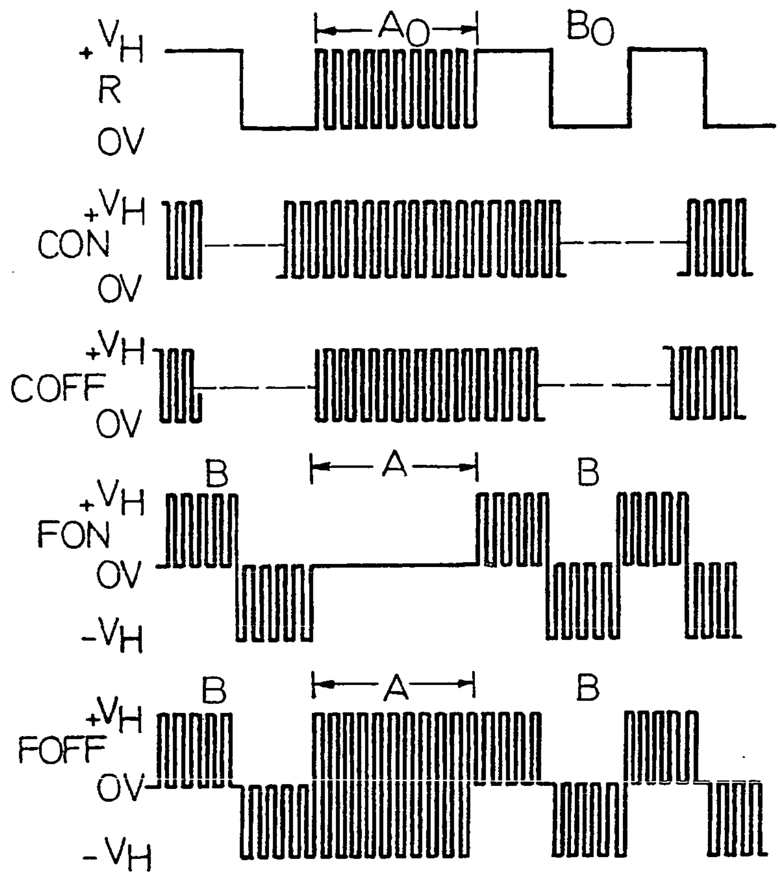


Fig. 2

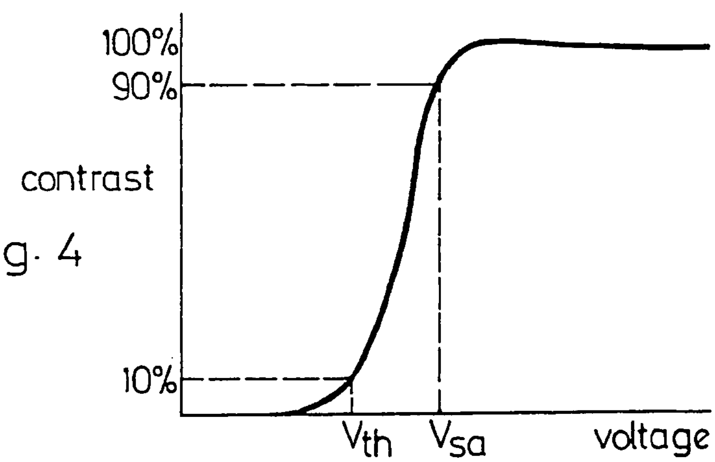


Fig. 4

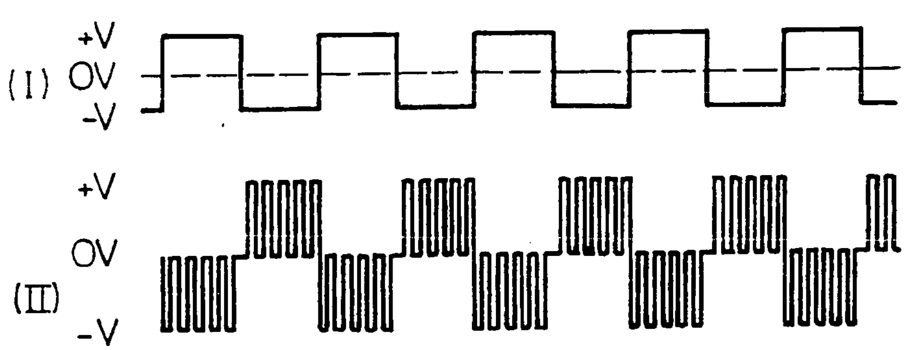


Fig. 3

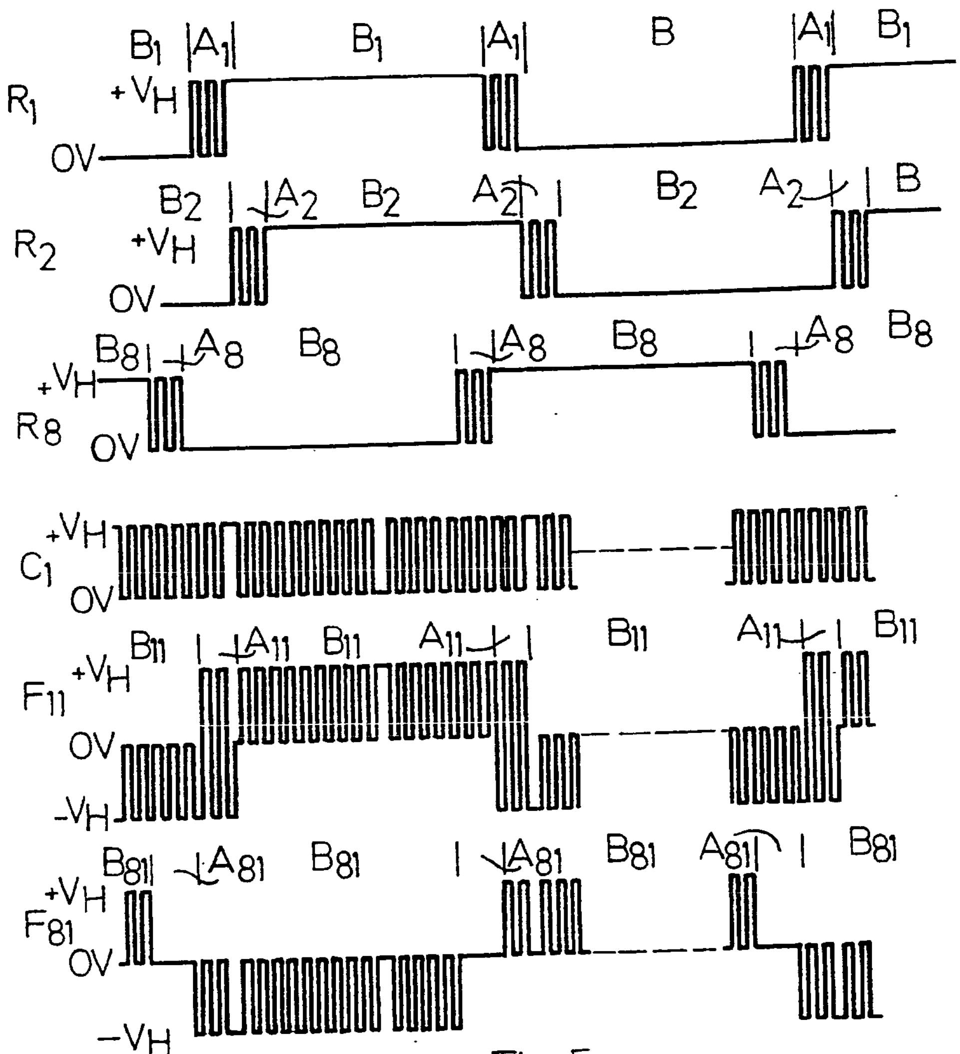

B1
A1
B1
A1
B
A1
B1
R1
+VH
OV
B2
A2
B2
A2
B2
A2
B
R2
+VH
OV
B8
A8
B8
A8
B8
A8
B8
+VH
R8
OV
C1
+VH
OV
B11
A11
B11
A11
B11
A11
B11
F11
+VH
OV
-VH
B81
A81
B81
A81
B81
A81
B81
+VH
F81
OV
-VH

Fig. 5

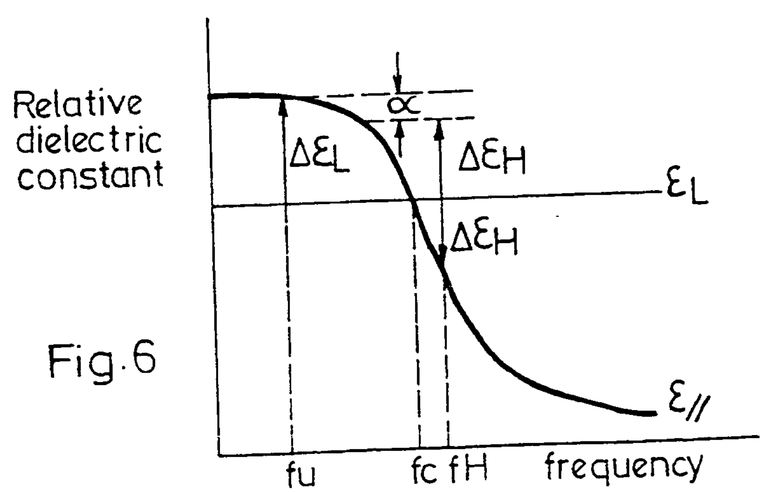
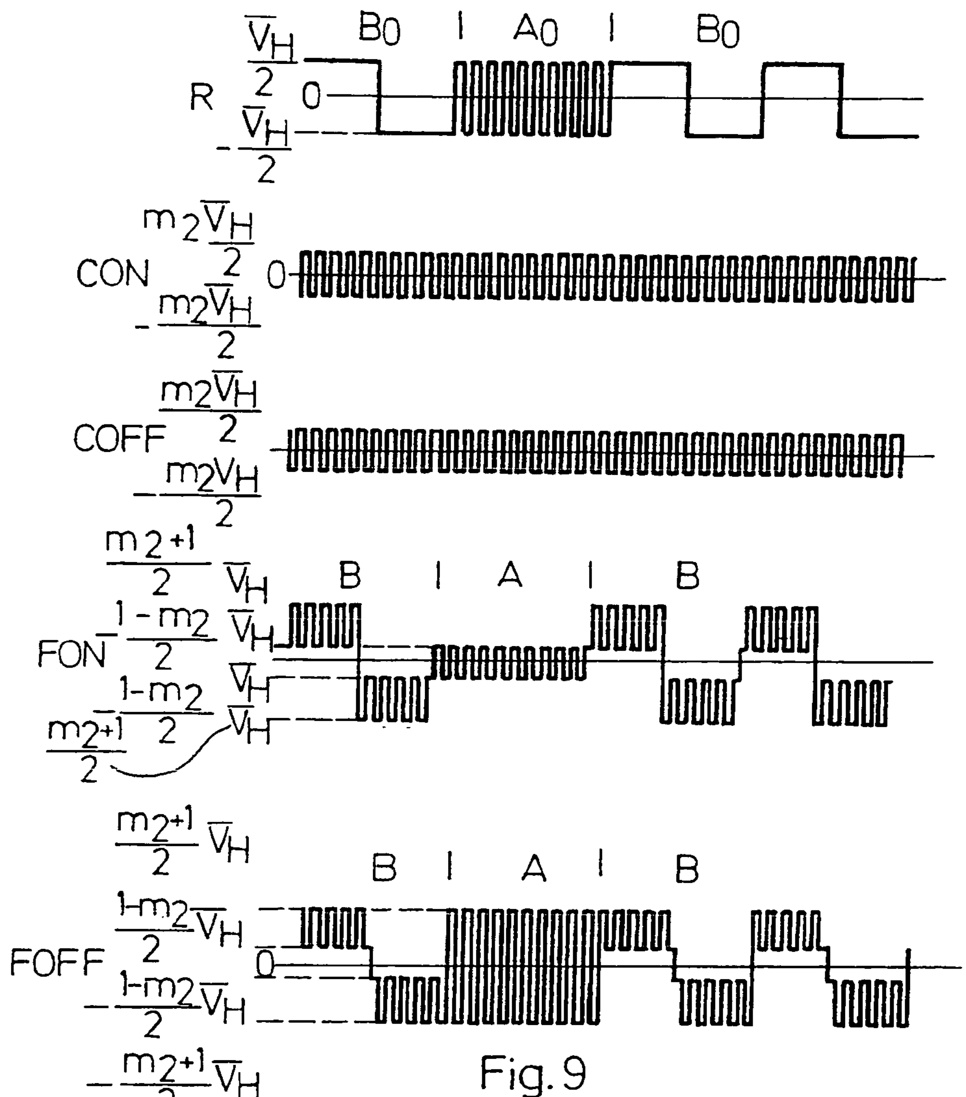
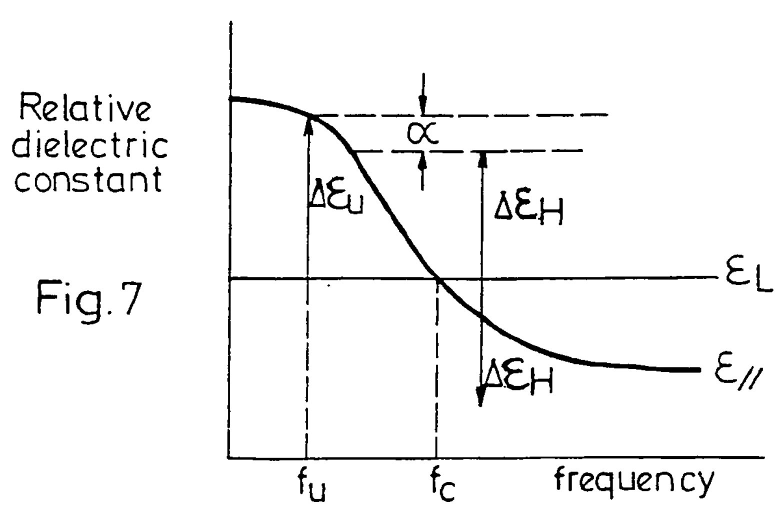

Relative
dielectric
constant
α
ΔεL
ΔεH
εL
ΔεH
ε//
fu
fc
fH
frequency

Fig. 6



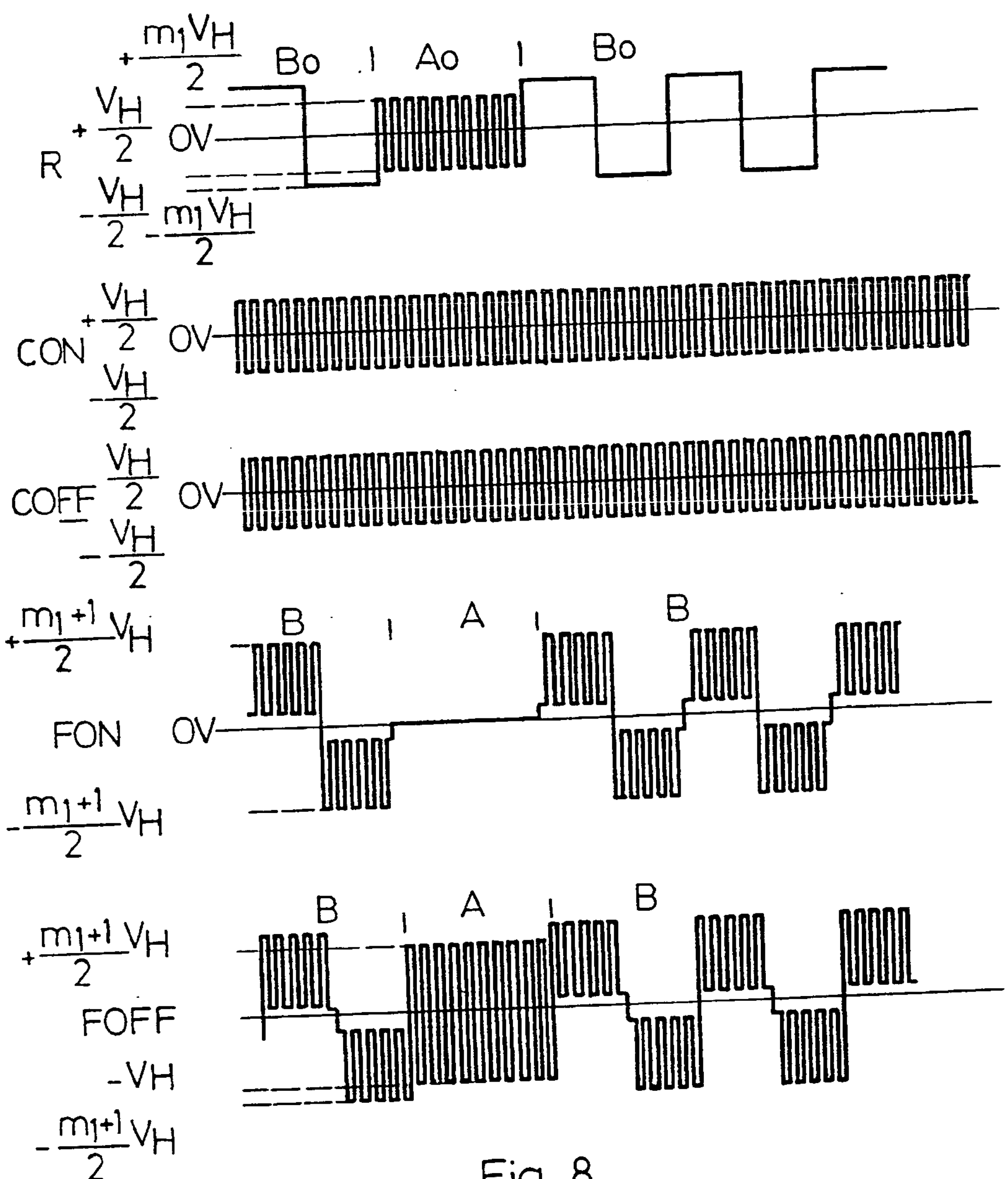
R
CON
COFF
FON
FOFF
B0
A0
B
A

Fig. 9



Relative dielectric constant
frequency

Fig. 7



$+\frac{m_1 V_H}{2}$
Bo
Ao
Bo
$+\frac{V_H}{2}$
OV
R
$-\frac{V_H}{2}$
$-\frac{m_1 V_H}{2}$
CON
$+\frac{V_H}{2}$
OV
$-\frac{V_H}{2}$
COFF
$\frac{V_H}{2}$
OV
$-\frac{V_H}{2}$
$+\frac{m_1+1}{2}V_H$
B
A
B
FON
OV
$-\frac{m_1+1}{2}V_H$
B
A
B
$+\frac{m_1+1}{2}V_H$
FOFF
-VH
$-\frac{m_1+1}{2}V_H$

Fig. 8

SPECIFICATION

Improvements in or relating to liquid crystal display systems

This invention relates to liquid crystal display systems and more specifically to such systems employing display devices which are of the matrix type and are addressed by two different frequencies. For convenience of reference such systems will be hereinafter termed two-frequency matrix display systems.

Liquid crystal display devices are nowadays widely used, notably in electronic desk and other calculators and in electronic wrist watches and other timepieces to provide displays such as digital displays of the results of calculation or digital displays of time. With liquid crystal matrix display devices providing a large number of picture points - e.g. with X - Y matrix display devices having large numbers of X and Y electrodes so as to provide a large number of picture points each at a crossing point of an X electrode with a Y electrode - it is in practice necessary to resort to multiplex driving, for otherwise the circuitry becomes excessively complex as regards the electrical connections required to the driving circuit and/or to the circuitry of the calculator or timepiece. Furthermore, in order to obtain a satisfactorily long useful life from the liquid crystal material employed, it is in practice necessary to resort to AC driving of the liquid crystal matrix display device. For these reasons it has become general to drive liquid crystal matrix display devices by the so-called AC amplitude selective multiplex method.

In order to obtain satisfactorily good contrast in the displayed "picture" produced by a liquid crystal matrix display device driven by a multiplex driving method the ratio (V_{ON}/V_{OFF}) must be high, where V_{ON} is the voltage which is applied between crossing electrodes to produce a displayed picture point at the crossing point and V_{OFF} is the voltage applied between said electrodes if a picture point is not to be produced at said crossing point. In other words, the ratio of the effective voltage value in the selected condition (V_{ON}) to that in the non-selected condition (V_{OFF}) must be high. The following equation expresses the ratio V_{ON}/V_{OFF} for best results in the case of a liquid crystal matrix display device driven by the known so-called AC amplitude selective multiplex method.

$$V_{ON}/V_{OFF} = \sqrt{\frac{\sqrt{n}+1}{\sqrt{n}-1}}$$

where n is the number of rows (the reciprocal of the duty ratio) in the matrix. As will be evident from the above equation the ratio V_{ON}/V_{OFF} becomes rapidly lower with increase in the number n of rows. If, for example, $n = 32$, $V_{ON}/V_{OFF} = 1.196$. However, the condition to be satisfied if acceptably good contract is to be obtained is $V_{ON}/V_{OFF} = 1.5$. This driving method is therefore not satisfactorily applicable to liquid crystal matrix display devices having a large number of lines and providing a large number of picture points. This is a serious limitation which it is the principal object of the present invention to avoid and the said invention seeks to provide improved liquid crystal matrix display systems which will provide good contrast in the displayed "pictures" even although the matrix has a large number of rows (or columns) and a large number of picture points.

Before explaining and describing the present invention reference will first be made to Figure Q of the accompanying drawings. This figure is a highly simplified purely schematic illustration showing the general nature of a liquid crystal display system having a matrix type display device. The display device comprises a set of horizontal (X) electrodes $X_1, X_2, X_3 .....X_n$ and a set of vertical (Y) electrodes $Y_1, Y_2, Y_3 .....Y_n$ crossing the X electrodes. There is a layer (not shown) of liquid crystal material between the two sets. If a suitable potential is applied between an X electrode and a Y electrode, a displayed dot or "picture point" is produced at a small area of the liquid crystal material where the two electrodes in question cross. The electrodes are addressed by timing signals from a timing signal source TS and data signals representative of the information to be displayed are supplied from a data signal source DS which might be, for example, constituted by the circuitry of an electronic timepiece. The sources TS and DS supply their outputs to control a suitable driving circuit arrangement DC providing display operating outputs to the X and Y electrodes. The whole arrangement is such that electrode crossing points in the display device are scanned in succession, the scannings being repeated and each scan occupying one frame period. If, during any frame period, a data signal to be displayed appears at the time when one X electrode (e.g. X_3) is addressed and one Y electrode (e.g. Y_3) is simultaneously addressed, a dot or picture point is displayed where these two electrodes cross. All this is, of course, well known and Figure Q does not itself form part of this invention. It is provided merely to facilitate understanding of the description and explanation of the invention to be given later herein. As will be apparent later, the invention does not reside in circuitry but in the signals which are employed to drive the display.

According to one aspect of the invention there is provided a liquid crystal display system having a matrix type liquid crystal display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a frequency range extending from 30Hz to 30KHz and is negative for frequencies above said frequency *fc* wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency *fc* and the other of which is a low frequency below said frequency *fc*, said low frequency being synchronised with an addressing timing signal

of the system. Preferably the period of the low frequency is an integral number of times the period of the addressing timing signal, i.e. the frame period but it is possible to obtain the low frequency and the high frequency from two oscillators, one for each frequency.

According to another aspect of the invention there is provided a liquid crystal display system having a liquid crystal matrix type display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a range extending from 30Hz to 30KHz and is negative for frequencies above said frequency *fc*, wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency *fc* and the other of which is a low frequency below said frequency *fc*, said high frequency being synchronised with an addressing timing signal of the system. Preferably in this case the addressing time is an integral number of times the period of said high frequency, but again, it is possible to obtain the low frequency and the high frequency from two oscillators, one for each frequency.

According to a further aspect of the invention there is provided a liquid crystal display system having a matrix type liquid crystal display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a range extending from 30Hz to 30KHz and is negative for frequencies above said frequency fc wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency fc and the other of which is a low frequency below said frequency fc, and wherein at least two of three voltage values, namely a voltage value (V_A) of a timing signal of the system in the selected condition (addressing time), the voltage value (V_B) of the timing signal in the non-selected condition and the voltage (V_C) of a data signal of the system are different from one another.

The invention is illustrated and explained in connection with the accompanying numbered drawings, in which :-

Figure 1 is a diagram showing the relation between frequency and relative dielectric constant of a typical liquid crystal material such as is employed in carrying out this invention;

Figure 2 is a diagram showing wave forms employed in two-frequency matrix-addressing;

Figure 3 shows basic wave forms employed in two-frequency matrix-addressing;

Figure 4 is a graph showing the relation between voltage and contrast in a liquid crystal display;

Figure 5 is a wave form diagram showing by way of example driving wave forms employed in two-frequency matrix-addressing in one system in accordance with this invention;

Figure 6 and 7 show examples of the relation between frequency and relative dielectric constant for two typical but different liquid crystal materials; and

Figures 8 and 9 are wave form diagrams illustrating driving wave forms employed in two-frequency matrix-addressing in a modified system in accordance with the invention.

Figure 1 shows graphically the relation between frequency and relative dielectric constant of a typical liquid crystal material which would be used in carrying out this invention. In Figure 1 $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ respectively represent the dielectric constant in the length direction and in the width direction of the liquid crystal molecule. The dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$) is positive ($\Delta\varepsilon_L > 0$) when the frequency is lower (e.g. at f_L) than a critical frequency (*fc*) at which the constant $\varepsilon_{\parallel}$ is equal to the constant $\varepsilon_{\perp}$, and is negative ($\Delta\varepsilon_H < 0$) when the frequency is higher (e.g. at f_H) than said critical frequency (*fc*). There now follows a description of a driving method for a liquid crystal matrix display device utilising a liquid crystal material having a frequency dependent characteristic as illustrated by Figure 1.

Referring to Figure 2, which shows an example of driving wave forms for a liquid crystal matrix display device employing a liquid crystal material with a characteristic as illustrated by Figure 1, R is a timing signal wave form. During the selected condition, i.e. in the condition in which a selected picture point is to be displayed, substantially rectangular high frequency waves as shown at A_0 are applied between the crossing electrodes at the selected point. During the non-selected condition, i.e. in the condition in which no display is to be produced at a crossing point of two electrodes, rectangular low frequency waves are applied as shown B_0. C_{ON} and C_{OFF} are respective data signals for the ON and OFF conditions. These are respectively in phase or 180° out of phase with the waves of the timing signal R in the addressing condition. Such correspondence of the wave form C_{ON} to the ON condition and the wave form C_{OFF} to the OFF condition is limited to liquid crystal displays wherein alignment of the liquid crystal molecules parrallel to the glass plate (the plate on which the liquid crystal material is positioned) occurs as in the so-called twisted nematic mode. As the result, the voltage applied to a liquid crystal picture cell (i.e. the area in the immediate neighbourhood of an electrode crossing point) is as shown at F_{ON} for the ON condition and F_{OFF} for the OFF condition. As will be seen F_{ON} is R - C_{ON} and F_{OFF} is R - C_{OFF}. The liquid crystal picture cell becomes OFF when the high frequency is applied in the addressing condition, and ON when no signal (i.e. O_V) is applied in the addressing condition.

With signals as represented in Figure 2, the effective voltage values in the ON and OFF conditions, and the ratio of those values, are given by the following equations

$$V_{ON} = V_L \sqrt{1 - 1/n} \quad \text{------} 1$$

$$V_{OFF} = \sqrt{V^2_L\,(1-\frac{1}{n}) + \frac{\Delta \varepsilon H}{\Delta \varepsilon L}\; V^2_H \cdot \frac{1}{n}} \text{ ------ } 2$$

$$V_{ON}/V_{OFF} = (1+\frac{1}{n-1} \cdot \frac{\Delta \varepsilon H \cdot V^2_H}{\Delta \varepsilon L \cdot V_L^2})^{-\frac{1}{2}} \text{ ----- } 3$$

In these equations n is the number of rows; V_L is a value of V (see Figure 3(I)) whereby a saturation voltage (Vsa of Figure 4) when a rectangular wave as shown in Figure 3(I) of frequency f_L ($<fc$) is applied as shown in the wave form R in the non-selected condition (B_o of Figure 2) is obtained: V_H is a value of V (see Figure 3(II)) whereby a saturation voltage Vsa when using a wave form (as shown at Figure 3(II)) is applied as shown at F_{ON} and F_{OFF} in the non-selected condition (B_o of Figure 2) is obtained; and $\Delta\varepsilon H$ and $\Delta\varepsilon L$ are the dielectric anisotropies (see Figure 1) respectively corresponding to the high frequency (f_H) and the low frequency (f_L).

Generally, the relation of the voltage Vsa to the dielectric anisotropy ($\Delta\varepsilon$) is as again given by the following equation :

$$V^2 sa = \gamma \cdot \frac{\pi^2 K}{\Delta \varepsilon \cdot \varepsilon_0} \text{ ------ } 4$$

where ε_0 is the dielectric constant in vacuum: K is the elastic constant of the liquid crystal material; and γ is the ratio (V^2sa/V^2th) of the voltage V^2sa to the voltage V^2th (see Figure 4). Vth being what may be termed the threshold voltage at which 10% contrast is obtained. The following equation applies:

$$\Delta \varepsilon L \cdot V_L^2 = \Delta \varepsilon L\,(\frac{V_H}{2})^2 + \Delta \varepsilon H \cdot (\frac{V_H}{2})^2 = \frac{\gamma \pi^2 K}{\varepsilon_0} (= a\ constant) \text{ --- } 5$$

Rearranging equation 5 we get

$$V_H = 2V_L \sqrt{\frac{\Delta \varepsilon L}{\Delta \varepsilon L + \Delta \varepsilon H}} \text{ ------ } 6$$

By substituting equation 5 in equation 3 we get:

$$V_{ON}/V_{OFF} = (1+\frac{4}{n-1} \cdot \frac{\Delta \varepsilon H}{\Delta \varepsilon L + \Delta \varepsilon H})^{-\frac{1}{2}} \text{ ------ } 7$$

This equation clearly shows that the larger $\left|\frac{\Delta \varepsilon H}{\Delta \varepsilon L + \Delta \varepsilon H}\right|$

becomes, the larger V_{ON}/V_{OFF} becomes. The importance of this will be at once apparent if equation 7 is compared with equation 1 for in equation 1 V_{ON}/V_{OFF} depends only on the number n of rows in the matrix.

A point about equation 3 should be noted. In this equation $\Delta\varepsilon \cdot V_L^2$ is a number fixed by equation 5. Therefore, V_{ON}/V_{OFF} can be made larger by making the values $\Delta\varepsilon H$ and V_H larger. However, as will be seen from equation 5 making $\Delta\varepsilon H/\Delta\varepsilon L$ close to zero is required for the value V_H to exist. It is possible theoretically to make V_{ON}/V_{OFF} larger without limitation if the value V_H is made large enough to bring the value $\Delta\varepsilon H/\Delta\varepsilon L$ close to zero. However, making V_H very large presents difficulties and disadvantages from the viewpoints of driving circuit design and practical use and, in practice, the value of V_H is determined by considerations of the largest service voltage to the driving circuit. Accordingly, it is desirable to find a condition for making V_{ON}/V_{OFF} as large as possible if V_H is of a selected constant value. The following equations can be obtained by rewriting the equations 3 and 5, assuming the adoption of a predetermined constant value for V_H.

$$V_{ON}/V_{OFF} = (1 + \frac{C_1}{n-1} \cdot \Delta \varepsilon H)^{-\frac{1}{2}} \text{ ------ } 8$$

$$C_1 = \frac{{V_H}^2}{\Delta \varepsilon L {V_L}^2} = \frac{\varepsilon_0\, {V_H}^2}{\pi^2 \cdot \gamma \cdot K}$$

$$\Delta\varepsilon L + \Delta\varepsilon H = \Delta\varepsilon L - |\Delta\varepsilon H| = C_2 \text{ .... } 9$$

$$C_2 = \frac{4\pi^2 \cdot \gamma \cdot K}{V_H{}^2 \cdot \varepsilon_0}$$

The following equation may be derived from the equations 8 and 9 :-

$$V_{ON}/V_{OFF} = \left\{1 + \frac{4}{n-1}\left(1 - \frac{\Delta\varepsilon L}{C_2}\right)\right\}^{-\frac{1}{2}} \text{ -------}10$$

In short, the larger $\Delta\varepsilon L$ is, the larger V_{ON}/V_{OFF} becomes and the smaller the value V_L becomes. As will be seen from Figure 1 if the frequency f_L is made small $\Delta\varepsilon L$ will be large. Accordingly (theoretically) $\Delta\varepsilon L$ becomes largest if $f_L = 0$ Hz, i.e. if direct current driving is used. But, as is well known, an alternating current drive is required if the liquid crystal material employed is to have a long useful life. It follows, therefore, that the voltage for application in the non-selected condition of the timing signal should be changed over at a suitable frequency. However, beat frequencies will be generated and flickering of the display will occur if the timing signal and the period of the above-mentioned changing of voltage in the non-selected condition of the timing signal are not synchronous. It is, accordingly, necessary for the changing over of the low frequency to be performed synchronously with the timing signal and this is therefore done. From the point of view of simple circuit design an excellent way of doing this is to make the period of the above-mentioned low frequency wave an integral number times as long as the period elapsing between one addressing condition and another addressing condition of the timing signal, namely a frame period. Figure 5, which illustrates one method in accordance with this invention, also illustrates this expedient. Here the voltage of the low frequency wave is changed over in fixed relation to the frame period, the period of the low frequency wave being twice as long as the frame period. (Strictly speaking, the period of the low frequency wave is equal to the difference between the frame period and the addressing time.)

Referring to Figure 5, R_1, R_2 ... R_8 show respectively timing signals for the first, second ..... eighth rows, the said figure showing driving signals for eight rows (1/8 duty ratio). C_1 shows a data signal for the first column, the data signal being in phase or 180° out of phase with the high frequency waves (A_1 to A_8) in the addressing condition of the respective timing signals corresponding to the ON and OFF conditions. As will be seen, signal F_{11} is applied to a picture cell in the first row and the first column, and signal F_{81} is applied to a picture cell in the eighth row and the first column. F_{11} shows a signal for the OFF condition, and F_{81} shows a signal for the ON condition. In both signals F_{11} and F_{81} the same low frequency waves are applied for twice as long a period as the frame period in the non-selected condition (B_{11}, B_{81}) and, in addition, almost the same high frequency waves are added to the wave forms. Such difference of the high frequency waves as does occur does so because the data signals are in phase or 180° out of phase with the addressing signals (A_1 to A_8) of the respective timing waves, but such difference is very small.

Attention is now directed once more to equation 5 above. In this equation the value $\Delta\varepsilon_H$ is determined in accordance with the value of $\Delta\varepsilon_L$, insofar as the value of V_H is not changed. That is to say, the values of $\Delta\varepsilon_L$ and $\Delta\varepsilon_H$ cannot be chosen at will and this in turn signifies that the frequencies f_L ($<fc$) and f_H ($>fc$) cannot be chosen at will. This is a considerable disadvantage as will be explained with the aid of Figures 6 and 7 which show the relative dielectric constant/frequency characteristics of two typical but different liquid crystal materials.

First the value $\Delta\varepsilon_L$ must be large, having regard to the driving voltage. Accordingly, the low frequency f_L is chosen at as low a value as possible. When the value f_L is chosen, the value of $\Delta\varepsilon_L$ is determined. The foregoing equation 5 can be rewritten as follows:

$$|\Delta\varepsilon_H| = \Delta\varepsilon_L - \left(\frac{2}{V_H}\right)^2 \cdot \frac{\gamma\pi^2 K}{\varepsilon_O} \text{ .... } 11$$

Here, the value α is assumed to be equal to $\left(\frac{2}{V_H}\right) \cdot \frac{\gamma\pi^2 K}{\varepsilon_O}$.

The value α shown in Figures 6 and 8 is of this value.

The value $\Delta\varepsilon_H$ is set as previously mentioned. Let f_H be the frequency which gives the value $\Delta\varepsilon_H$. But as will be seen from Figure 6 the value $\Delta\varepsilon_H$ changes considerably with a relatively small change in the frequency f_H. On the other hand, as will be seen from Figure 7, a frequency f_H which satisfies the value $\Delta\varepsilon_H$ does not exist. Now re-write equation 5 as follows:-

$$\Delta\varepsilon_L V_L = \Delta\varepsilon_L \cdot \left(\frac{m_1 V_H}{2}\right)^2 + \Delta\varepsilon_H \cdot \left(\frac{m_2 V_H}{2}\right)^2 = \frac{\gamma\pi^2 K}{\varepsilon} \text{ .... } 12$$

where m_1 and m_2 are proportionality factors. The significance of equation 12 is that it gives the voltage (hereinafter referred to as V_B) of the timing signal in the non-selected condition as set at $\frac{m_1 V_H}{2}$ and the voltage (hereinafter referred to as V_C) of the data signal as set at $\frac{m_2 V_H}{2}$, when the voltage of the timing signal (hereinafter referred to as V_A) in the selected condition is $\frac{V_H}{2}$.

Figure 8 shows the driving wave forms used when $m_2 = 1$, that is $V_A = V_C$. The signals R, C_{ON}, C_{OFF}, F_{ON},

F_{OFF} correspond with the similarly referenced signals in Figure 2. In Figure 8 the voltage value of the timing signal (R) in the non-selected condition (Bo) is set at $m_1 \cdot \frac{V_H}{2}$. As the result, the wave forms of the signals F_{ON} and F_{OFF} applied to the liquid crystal picture cell in the non-selected condition (B) in Figure 8 are different from those in Figure 2. But the wave forms of the signals F_{ON} and F_{OFF} in the selected condition (A) in Figure 8 are the same as those in Figure 2. Therefore, the voltage values V_{ON}, V_{OFF} and the ratio V_{ON}/V_{OFF}, and the voltage values of the frequencies in Figure 2 can be respectively expressed by the equations 1, 2 and 3 already given. However, the value $\Delta\varepsilon_H$ and the factor m_1 must satisfy the equation:

$$\Delta\varepsilon_L V_L^2 = \Delta\varepsilon_L \left(\frac{m_1 \cdot V_H}{2}\right)^2 + \Delta\varepsilon_H \cdot \left(\frac{V_H}{2}\right) = \frac{\gamma\pi^2 K}{\varepsilon} \text{..... } 13$$

Thus the values of $\Delta\varepsilon_L$ and $\Delta\varepsilon_H$ can be chosen at will by introducing a suitable factor m_1.

Figure 9 shows the driving wave forms used when $m_1 = 1$, that is $V_A = V_B$. With m_1 chosen as equal to 1, the wave forms of the signals F_{ON} and F_{OFF} in the selected condition (A) are different from those shown in Figures 2 and 8. The values of V_{ON}, V_{OFF} and V_{ON}/V_{OFF} in Figure 9 will be clear from what follows.

First, re-write equations 1 and 2 as follows by substituting therein equation 5. Then equation 1 becomes :-

$$V_{ON} = \sqrt{\frac{n-1}{n}\left(\frac{V_H}{2}\right)^2\left(1 - \frac{|\Delta\varepsilon_{Hc}|}{\Delta\varepsilon_L}\right)} \text{ ---------- } 14$$

and equation 2 becomes:-

$$V_{OFF} = \sqrt{\frac{n-1}{n}\left(\frac{V_H}{2}\right)^2\left(1 - \frac{|\Delta\varepsilon_{Hc}|}{\Delta\varepsilon_L}\right) - \frac{1}{n}\,\frac{|\Delta\varepsilon_{Hc}|}{\Delta\varepsilon_L}\,V_H^2} \text{ ----- } 15$$

In both these equations the value of $\Delta\varepsilon_{Hc}$ is that which satisfies equation 5. This value also satisfies the relation in the following equation 16 in which the values of $\Delta\varepsilon_L$ and V_H are constants so that the value of $\Delta\varepsilon_{Hc}$ is constant also.

$$\Delta\varepsilon_L V_L^2 = \Delta\varepsilon_L \left(\frac{V_H}{2}\right)^2 - |\Delta\varepsilon_H \left(\frac{V_H}{2}\right)^2 = \frac{\gamma\pi^2 K}{\varepsilon} (= \text{constant}) \text{ .... } 16$$

Next, the values V_{ON} and V_{OFF} in Figure 9 may be expressed by the following equations:-

$$V_{ON} = \sqrt{\frac{n-1}{n}\left(\frac{V_H}{2}\right)^2\left(1 - \frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L}m_2^{\,2}\right) - \frac{1}{n}\,\frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L}(1-m_2^{\,2})\left(\frac{V_H}{2}\right)^2} \text{ ------- } 17$$

$$V_{OFF} = \sqrt{\frac{n-1}{n}\left(\frac{V_H}{2}\right)^2\left(1 - \frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L}m_2^{\,2}\right) - \frac{1}{n}\,\frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L}(1+m_2)^2\left(\frac{V_H}{2}\right)^2} \text{ ---- } 18$$

The value of $\Delta\varepsilon_H$ in these equations is different from the value $\Delta\varepsilon_{Hc}$, because of the introduction of the constant m_2. If, however, $m_2 = 1$, $\Delta\varepsilon_H = \Delta\varepsilon_{Hc}$. Here the value V_{ON} in equation 17 must be higher than the value Vsa shown in Figure 4 and the value V_{ON} in equation 17 and the value V_{ON} in equation 1 must be equal. From this, the following relations are obtained:-

$$|\Delta\varepsilon_H| = \frac{(n-1)\,|\Delta\varepsilon_{Hc}|}{n.m_2^{\,2} - 2m_2 + 1} \text{ -------- } 19$$

$$m_2 = \sqrt{\frac{1}{n} + \frac{1}{n^2} - \frac{1}{n} + \frac{n-1}{n}\,\frac{|\Delta\varepsilon_{Hc}|}{\Delta\varepsilon_H}} \text{ -------- } 20$$

Accordingly equations 17 and 18 can be rewritten as follows:-

$$V_{ON} = \sqrt{\frac{n-1}{n} V_L^{\,2}} \text{ ------------ } 21$$

and

$$V_{OFF} = \sqrt{\frac{n-1}{n} V_L^{\,2} - m_2 \frac{1}{n} \frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L} \cdot V_H^{\,2}} \text{ ------- } 22$$

The equation 21 is effectively equal to equation 1, but equation 22 includes the term V_H^2 multiplied by m_2 and is therefore effectively different from equation 2. The ration V_{ON}/V_{OFF} can be expressed as follows:-

$$V_{ON}/V_{OFF} = \left(1 - \frac{m_2}{n-1} \frac{|\Delta\varepsilon_H|}{\Delta\varepsilon_L} \frac{V_H^{\,2}}{V_L^{\,2}}\right)^{-\frac{1}{2}} \text{ --------- } 23$$

From this condition for which the ratio V_{ON}/V_{OFF} in equation 23 will be a maximum can be obtained from the following equations:-

$$\left.\begin{aligned} m_2 &= 1/\sqrt{n} \\ |\Delta\varepsilon_H| &= \frac{n+\sqrt{n}}{2} \cdot |\Delta\varepsilon_{Hc}| \end{aligned}\right\} \text{ -------------- } 24$$

That is to say, the ratio V_{ON}/V_{OFF} becomes a maximum when the voltage of the data signal is $1/\sqrt{n}$ times as great as the voltage of the timing signal, and the dielectric anisotropy of the high frequency is $\frac{n+\sqrt{n}}{2}$ times as great as the value $\Delta\varepsilon_{Hc}$.

The following equation is obtained by substituting the equation 24 into equation 23.

$$V_{ON}/V_{OFF} = \left(1 - \frac{\sqrt{n}+1}{2} \cdot \frac{1}{n-1} \frac{|\Delta\varepsilon_{Hc}|}{\Delta\varepsilon_L} \frac{V_H^{\,2}}{V_L^{\,2}}\right)^{-\frac{1}{2}} \text{ ..... } 25$$

From equation 3 it follows that the ratio of the voltages (V_{OV}/V_{OFF}) becomes higher proportionally as the number (n) of rows is increased. This is a considerable advantage. A further advantage is that the load on the driving circuit is decreased and that a low value of display element driving voltage can be used if the voltage of the data signal is made lower than the voltage of the timing signal.

The foregoing description relates to the obtaining of the (maximum) value of the ratio V_{ON}/V_{OFF}. However in cases in which the value V_{ON}/V_{OFF} does not need to be the maximum, values of $\Delta\varepsilon_L$ and $\Delta\varepsilon_H$ and therefore of the frequencies f_L and f_H, can be chosen at will by choosing a factor m_2 to satisfy equation 19 or 20 for the optionally chosen value of $\Delta\varepsilon_H$.

Thus, by introducing the factors m and m_2 for the value V_H, a high value of the ratio V_{ON}/V_{OFF} can be obtained when using a liquid crystal material having, for example, a characteristic as shown in Figure 6 or 7 and a ratio (V_{ON}/V_{OFF}) considerably higher than that obtainable with a conventional two-frequency matrix-addressing system operating as described above with reference to Figure 2, can be obtained.

Hereinbefore it has been assumed that driving of the liquid crystal is performed in the twisted nematic mode (TN) with the crystal molecules aligned horizontally, i.e. parallel to the glass plate on which the liquid crystal layer is positioned. However, the invention is equally applicable to displays with the liquid crystal material driven in the Guest-Host mode (i.e. with the molecules vertically aligned) and dichroic dye added to the liquid crystal material. In such a case the high frequency should be used for the timing signal in the selected condition and for the data signal and the low frequency should be used for the timing signal in the non-selected condition.

The invention can be carried into practice not only as above described but also with the low frequency used for the timing signal in the selected condition and for the data signal, and the high frequency used for the timing signal in the non-selected condition.

Among the advantages of the invention are that substantially no variation in contrast as between different picture cells is obtained because the wave forms in the non-selected condition are always almost the same and that the ratio V_{ON}/V_{OFF} can be made of maximum value for a given driving voltage so that considerably better contrast in the displayed picture, as compared with that of a display driven in accordance with the conventional AC amplitude selective multiplexing method is obtainable. Also, by using a driving method as hereinbefore explained with the aid of Figures 8 and 9 it is possible to select the high frequency and the low frequency at will without change of the voltage ratio (V_{ON}/V_{OFF}) in the two-frequency matrix-addressing, i.e. without adversely affecting the good contrast obtainable.

CLAIMS

1. A liquid crystal display system having a matrix type liquid crystal display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a frequency range extending from 30Hz to 30KHz and is negative for frequencies above said frequency *fc* wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency *fc* and the other of which is a low frequency below said frequency *fc*, said low frequency being synchronised with an addressing timing signal of the system.

2. A system as claimed in claim 1 wherein the period of the low frequency is an integral number of times the period of the addressing timing signal, i.e. the frame period.

3. A liquid crystal display system having a liquid crystal matrix type display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a range extending from 30Hz to 30KHz and is negative for frequencies above said frequency *fc*, wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency *fc* and the other of which is a low frequency below said frequency *fc*, said high frequency being synchronised with an addressing timing signal of the system.

4. A system as claimed in claim 3 wherein the addressing time is an integral number of times the period of said high frequency.

5. A system as claimed in claim 1 or 3 wherein the low frequency and the high frequency are obtained from two oscillators, one for each frequency.

6. A liquid crystal display system having a matrix type liquid crystal display device driven with two-frequency matrix-addressing and comprising a liquid crystal composition the dielectric anisotropy of which changes with frequency and is positive for frequencies below a critical frequency *fc* within a range extending from 30Hz to 30KHz and is negative for frequencies above said frequency *fc* wherein said two-frequency matrix-addressing is effected by two frequencies one of which is a high frequency above said frequency *fc* and the other of which is a low frequency below said frequency *fc*, and wherein at least two of three voltage values, namely a voltage value (V_A) of a timing signal of the system in the selected condition (addressing time), the voltage value (V_B) of the timing signal in the non-selected condition and the voltage (V_C) of a data signal of the system are different from one another.

7. A system as claimed in claim 6 wherein said voltage V_A is chosen equal to the voltage V_C and both are chosen different from the voltage V_B.

8. A system as claimed in claim 6 wherein the voltage V_A is chosen equal to the voltage V_B and both are chosen different from the voltage V_C.

9. An electronic timepiece providing a digital time display and including a system as claimed in any of claims 1 to 8.

10. An electronic calculator including a system as claimed in any of claims 1 to 8.

11. Liquid crystal display systems as claimed in any of claims 1 to 8 and electronic timepieces and calculators including the same, substantially as herein described with reference to the accompanying drawings.

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